WCRP World Climate Research Programme

CMIP6

CMIP6 Analysis Online Seminar

Friday 15 May

Met Office

UKESM

UKRI Natural Environment Research Council

WCRP World Climate Research Programme

CMIP6

Steven Turnock

Met Office Hadley Centre

Met Office

UKESM

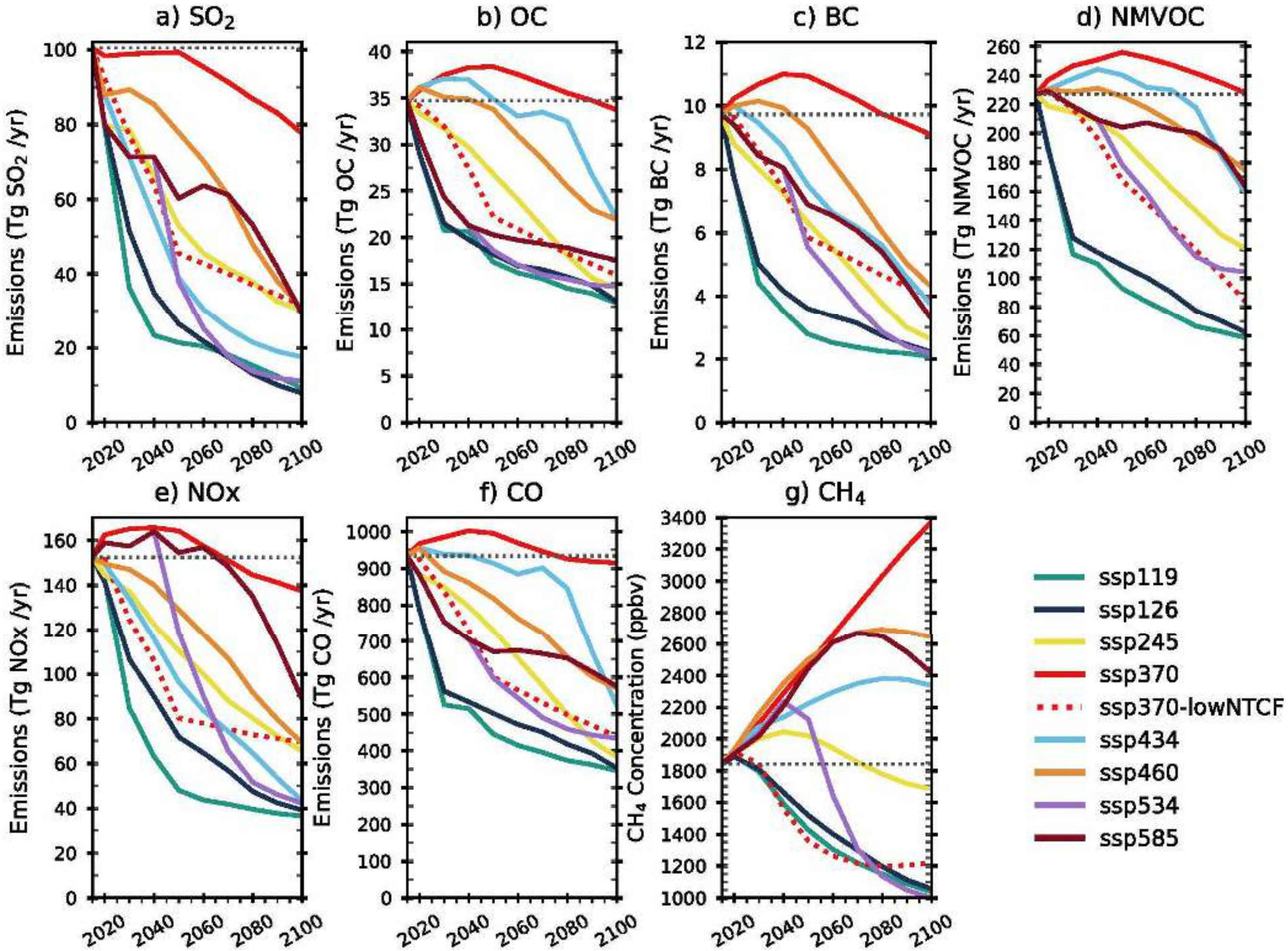
UKRI Natural Environment Research Council

Air Pollutants in CMIP6 Models

Met Office Hadley Centre

- Air pollutants impact human health, ecosystems and climate.
- Meteorology/climate can also influence air pollutants
- Assess changes in Particulate Matter (PM) and Ozone (O_3 - tropospheric) across CMIP6 scenarios used in latest models

Global air pollutants emissions across CMIP6 scenarios



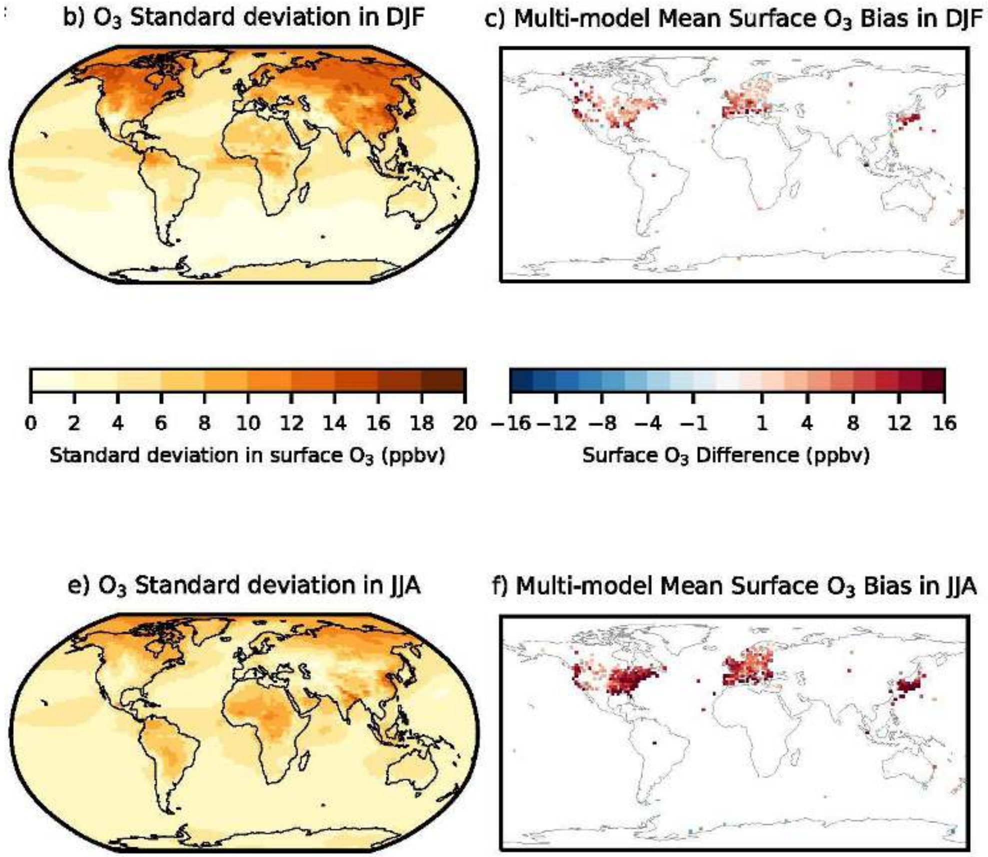
- CMIP6 covers wider range of air pollutant trajectories than CMIP5

Turnock et al., (2020) – ACPD (https://doi.org/10.5194/acp-2019-1211)

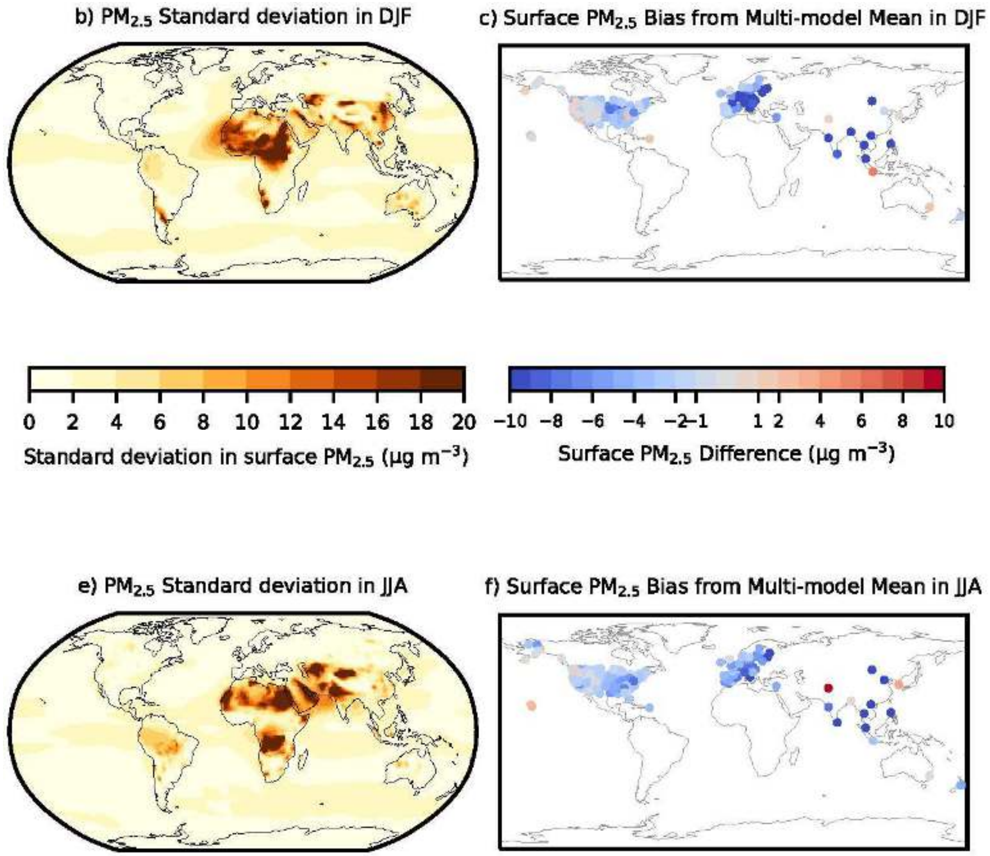
Met Office Hadley Centre

Present Day Model Evaluation

2005-14 seasonal surface O_3 from 5 CMIP6 models



2000-10 seasonal surface $PM_{2.5}$ from 10 CMIP6 models



CMIP6 models consistently overestimate surface O_3 observations

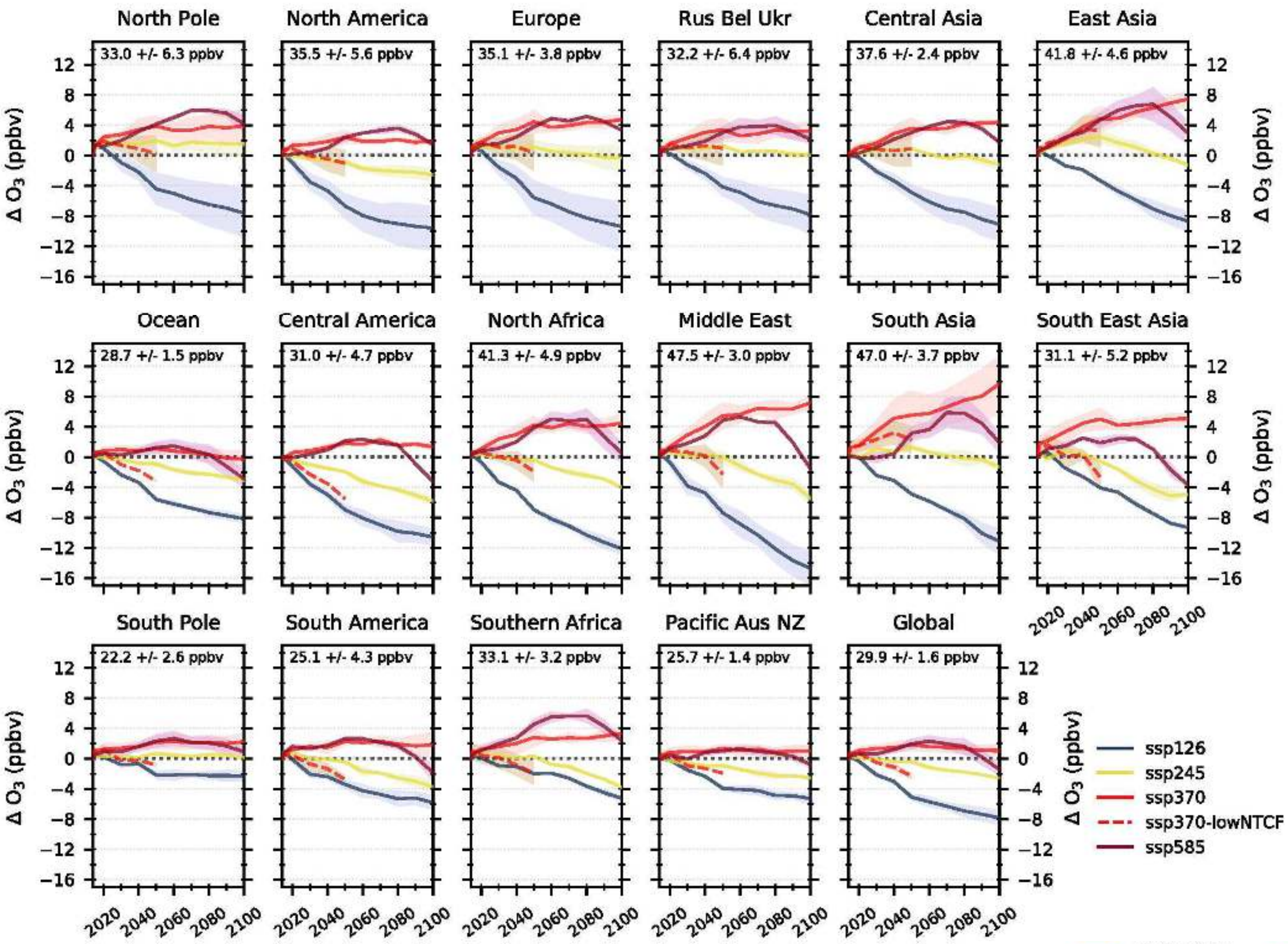
CMIP6 models consistently under estimate surface $PM_{2.5}$ observations

Turnock et al., (2020) – ACPD (https://doi.org/10.5194/acp-2019-1211)

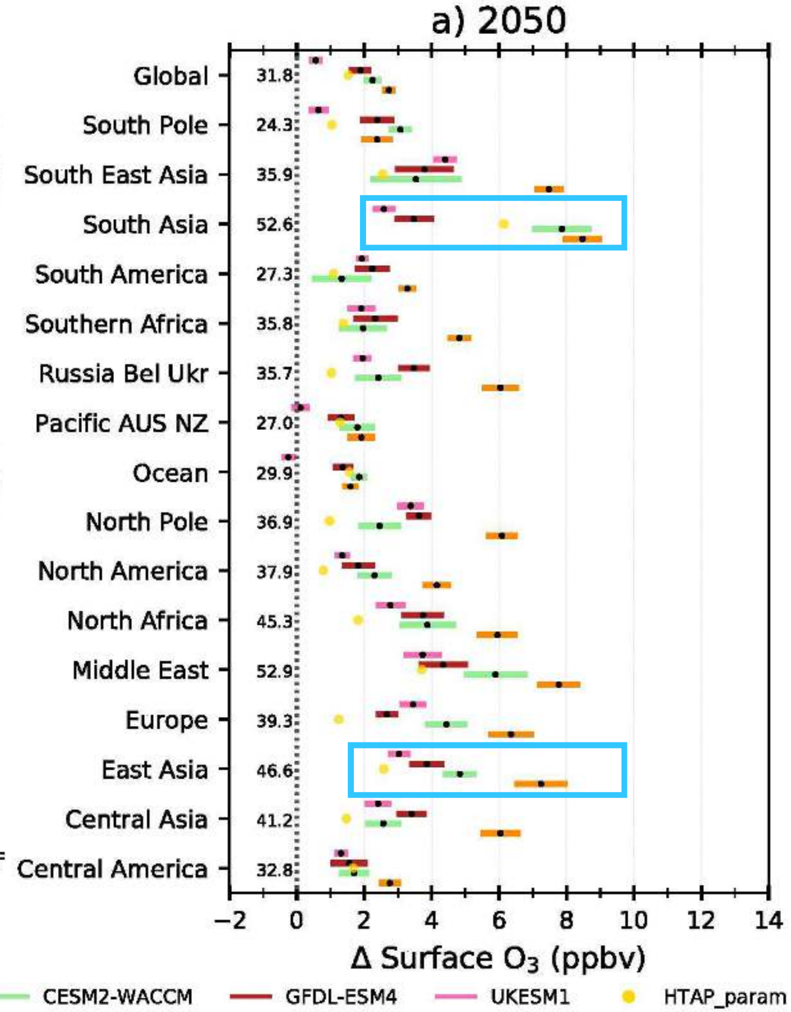
30 years
Leading climate science and services in our changing world

Future Changes in Surface O_3

Multi-model annual mean response in all scenarios



Individual model response in ssp370



Regional surface O_3 increases in ssp370 and ssp585 with reductions in ssp126

Largest diversity over East and South Asia

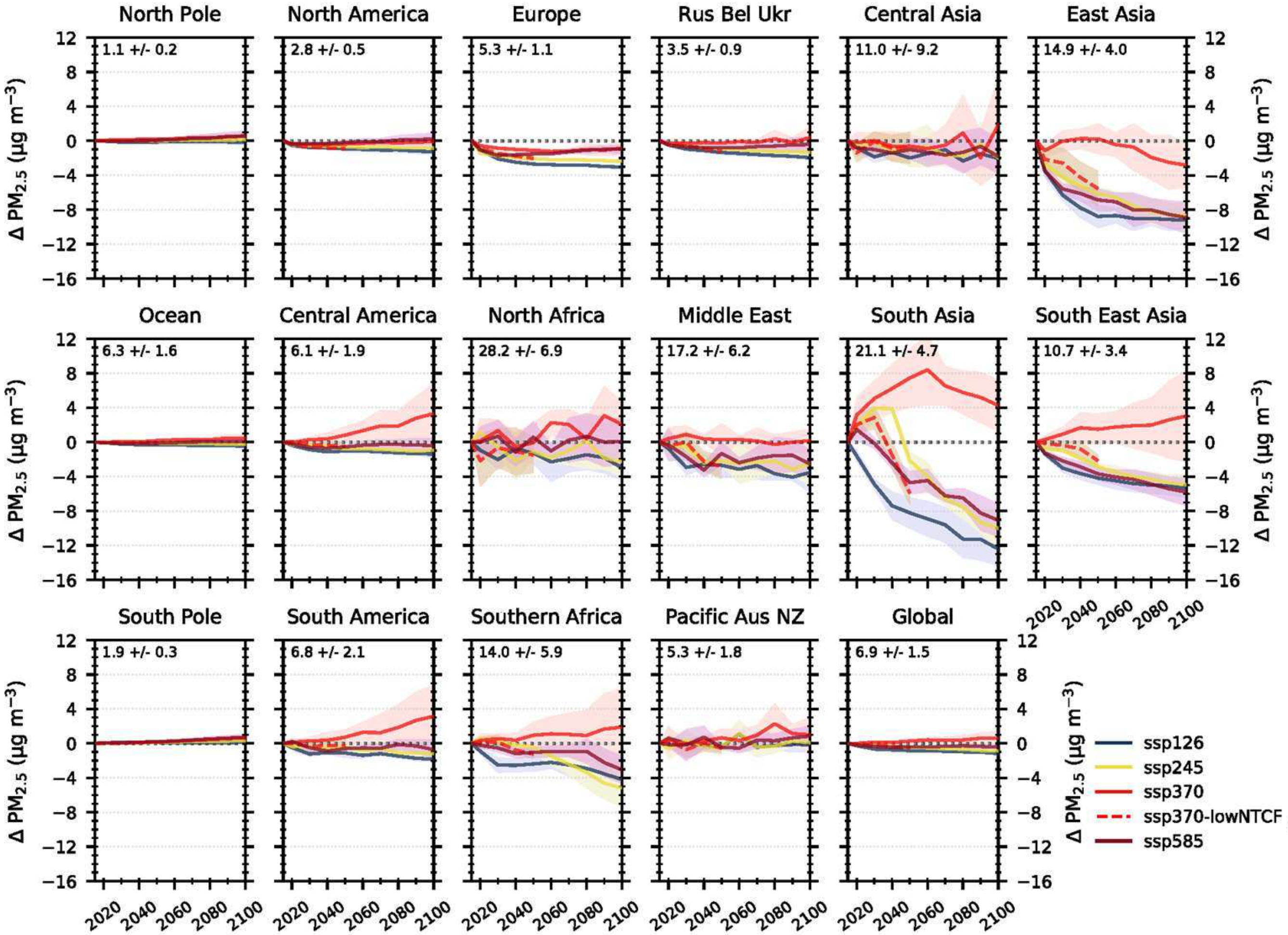
Further work to understand model diversity and drivers of change

30 years
Leading climate science and services in our changing world

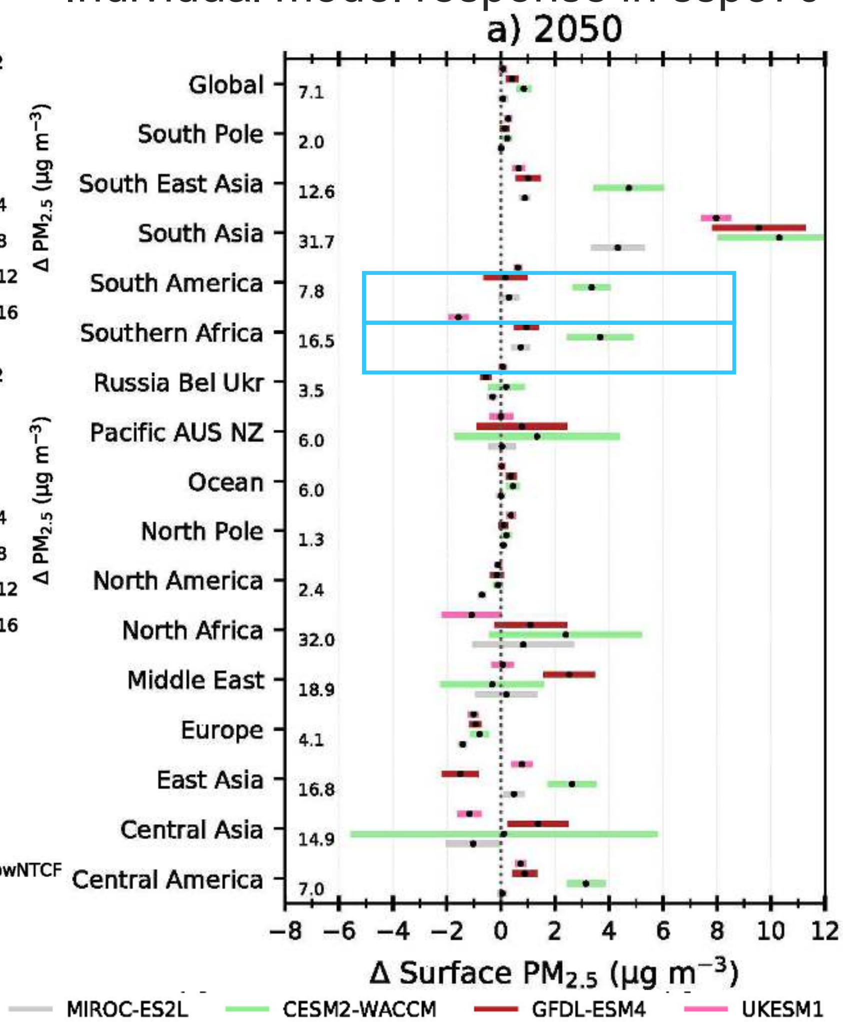
Met Office Hadley Centre

Future Changes in Surface $PM_{2.5}$

Multi-model annual mean response in all scenarios



Individual model response in ssp370



Most regions show decrease in surface $PM_{2.5}$ for all scenarios but some increases in ssp370 over Asia

Disagreement in response over certain regions

Further work on differences in model response over natural source regions

30 years Leading climate science and services in our changing world

WCRP
World Climate Research Programme
CMIP6

Jonathan Beverley
University of Exeter

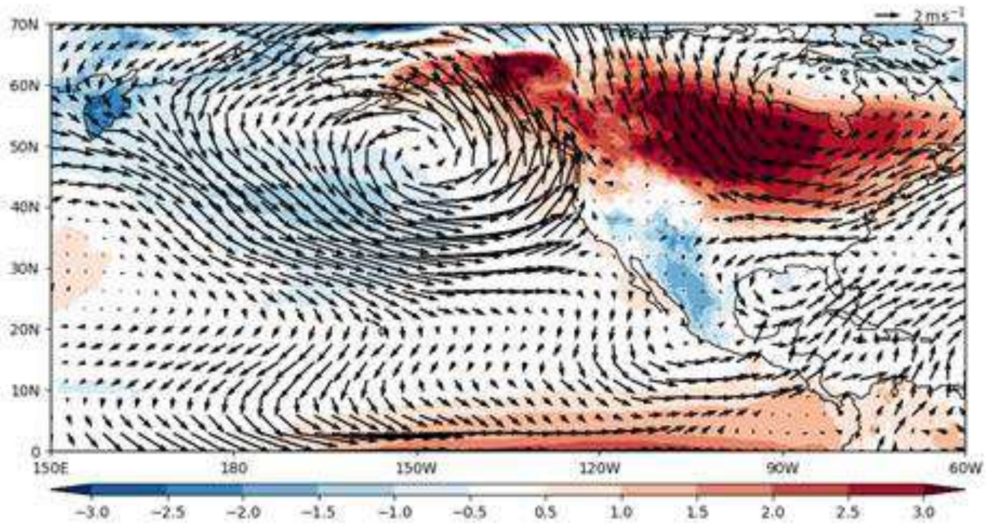
Met Office
UKESM
UKRI Natural Environment Research Council

Future changes in ENSO teleconnections over the North Pacific and North America in CMIP6 simulations

Jonathan Beverley, Mat Collins, Hugo Lambert & Rob Chadwick

Overview

ERA5 El Niño temperature, wind anomalies



- El Niño-Southern Oscillation (ENSO) has major impacts on the weather and climate in North America
- It is therefore important to understand how these teleconnections may change in the future

- We use data from 17 CMIP6 models:
    - Pre-industrial control (piControl) – 450 years of data, with CO_2 concentrations set to represent conditions in 1850
    - abrupt-4xCO2 – 75 years of data, with CO_2 concentrations quadrupled from the global annual mean 1850 value
- We focus here on northern hemisphere winter (DJF)
- A year is defined as an El Niño year if the Niño 3.4 Index exceeds one standard deviation of the piControl DJF Niño 3.4 Index time series

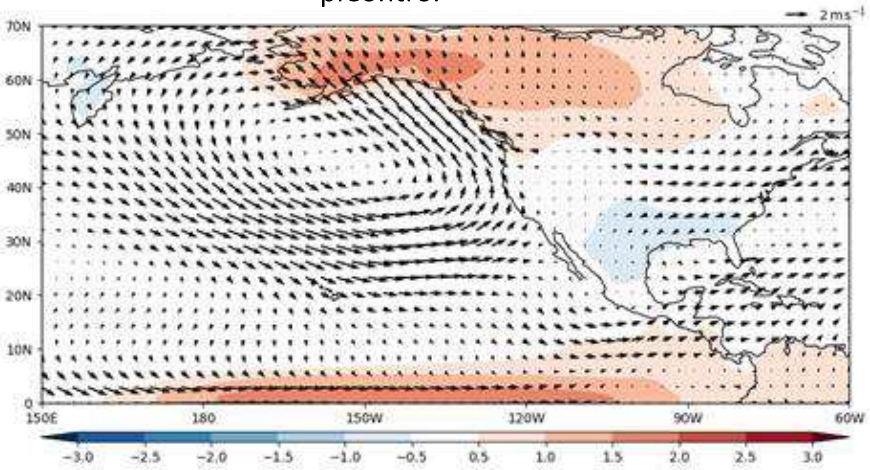
j.d.beverley@exeter.ac.uk @JBeverley93

Future teleconnection changes

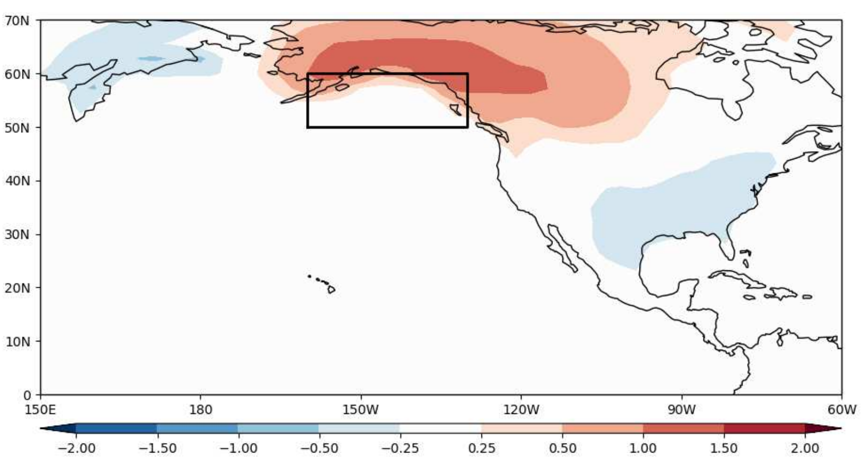
El Niño temperature, 850 hPa wind anomalies

Temperature regressed against 850 hPa meridional wind (box)

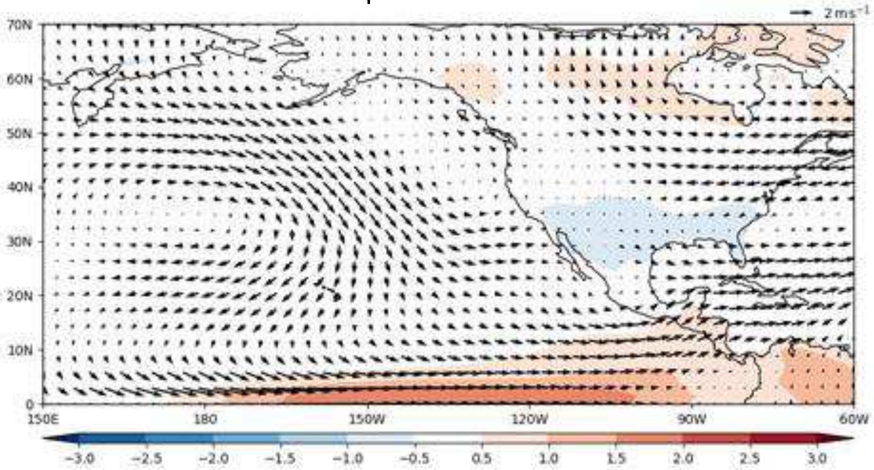
piControl



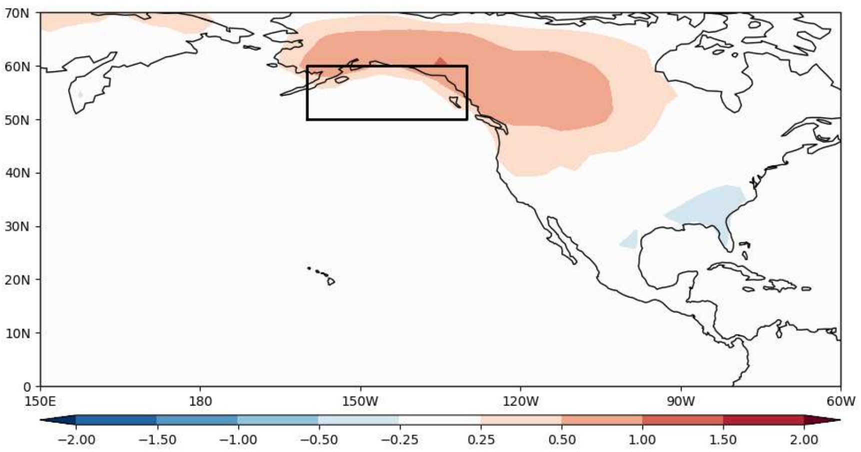
piControl



abrupt-4xCO2



abrupt-4xCO2

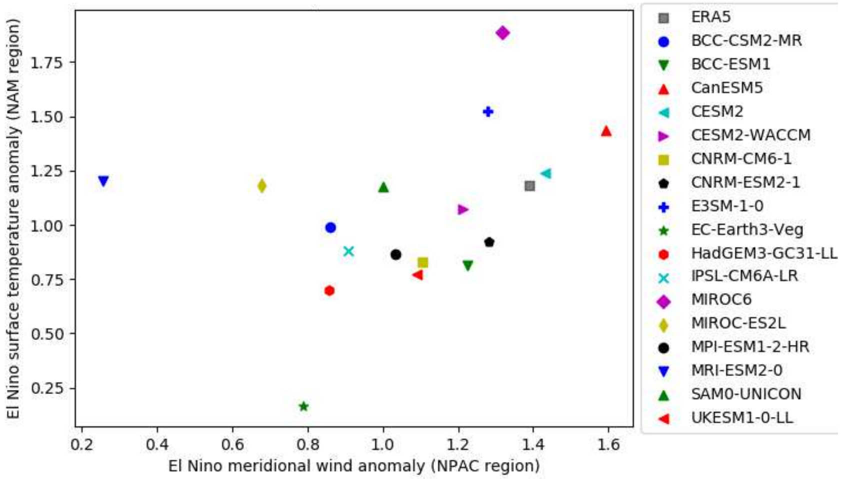


- In the abrupt-4xCO2 simulations, the temperature anomalies in El Niño years over northern North America are much weaker (15 out of 17 models agree on sign of change) – left column
- Partly associated with an eastward shift of the teleconnection pattern, as El Niño precipitation shifts eastwards due to faster warming in the eastern Pacific, and partly a weakening of circulation anomalies in some models
- Relationship between North Pacific meridional wind and North America temperature slightly weaker in abrupt-4xCO2 (right column), suggesting some external influence, but circulation changes dominant

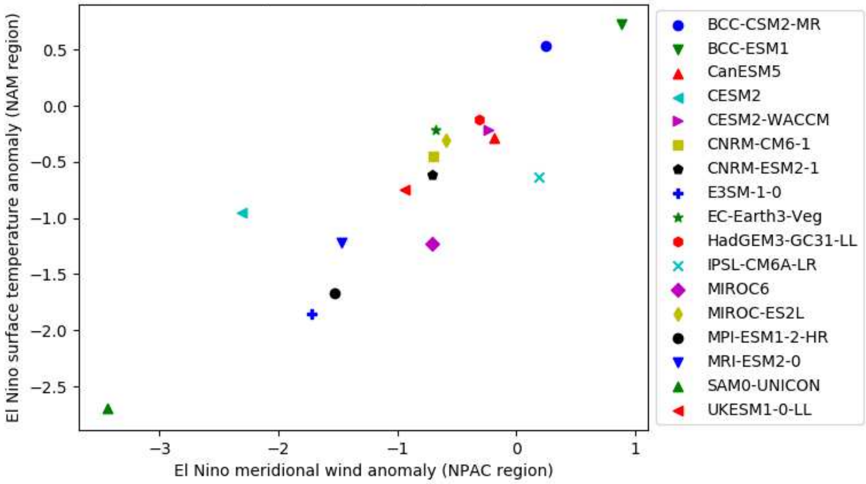
j.d.beverley@exeter.ac.uk @JBeverley93

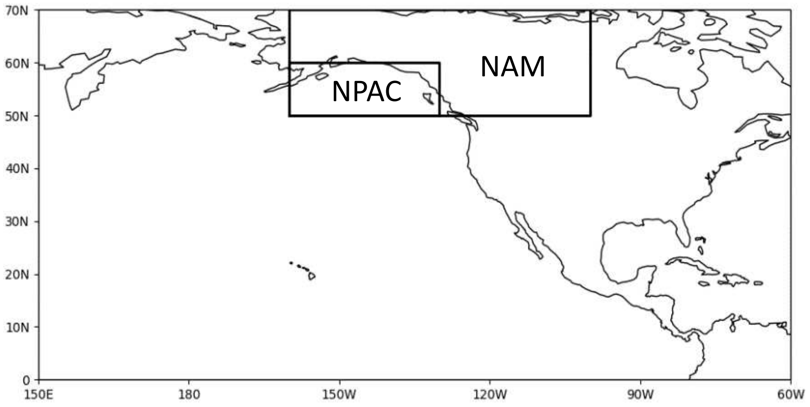
Future teleconnection changes

piControl



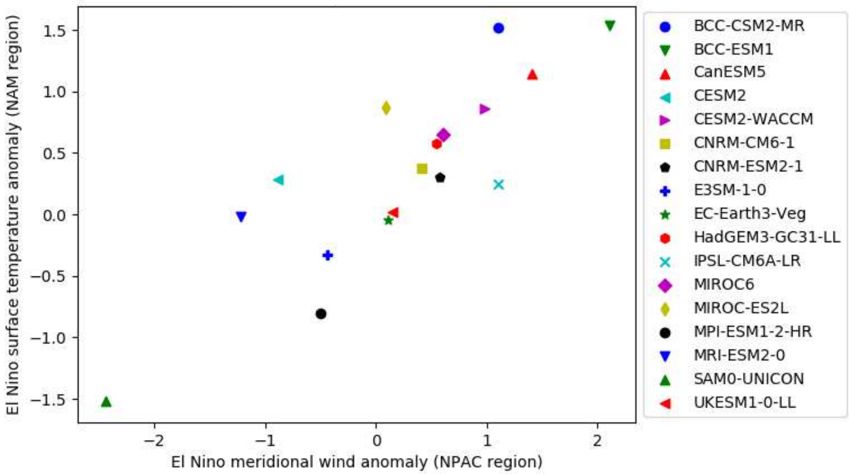
abrupt-4xCO2 minus piControl





NPAC (North Pacific) region = 50-60N, 160-130W
NAM (North America) region = 50-70N, 160-100W

abrupt-4xCO2



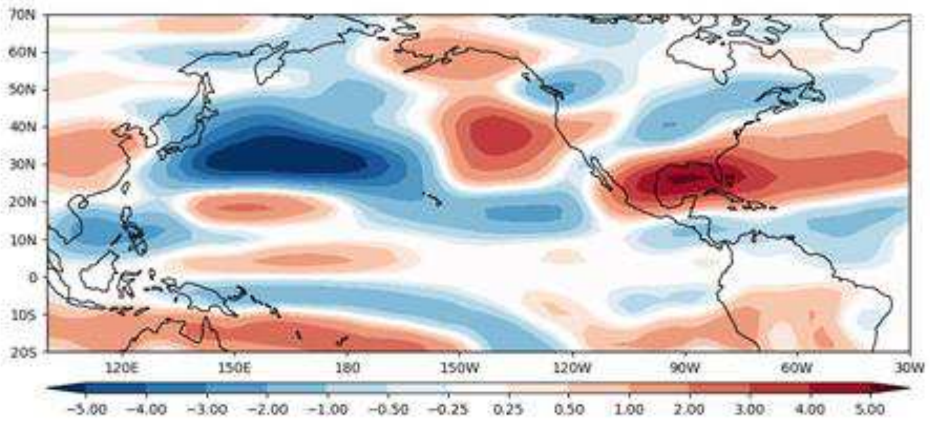
- Magnitude of temperature anomalies over North America in El Niño years is closely related to the strength of the wind anomalies over the North Pacific, in almost all models, in both piControl and abrupt-4xCO2
- This is also true when looking at the difference between piControl and abrupt-4xCO2
- This suggests that changes to El Niño circulation anomalies under global warming are the dominant cause of changes to the strength of the temperature anomalies over North America, as opposed to changes in the temperature gradient (i.e. high latitudes warming faster than low latitudes)

j.d.beverley@exeter.ac.uk @JBeverley93

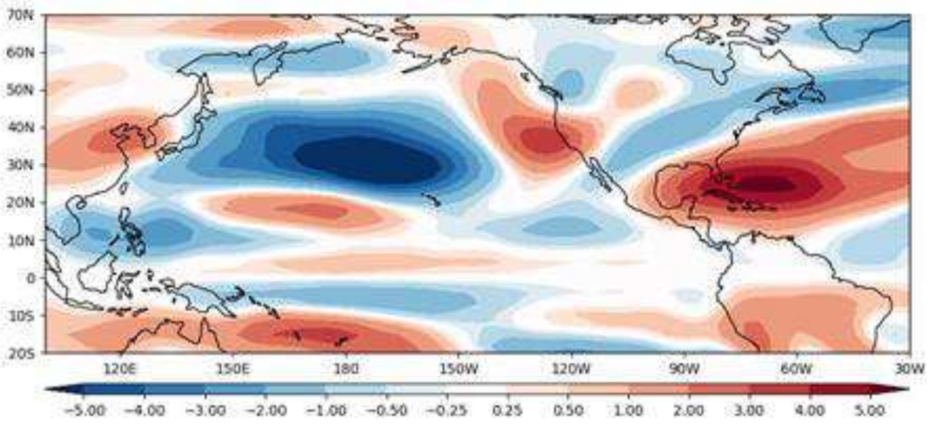
Possible cause – weaker forcing?

El Niño fD anomalies

piControl



abrupt-4xCO2



- Despite overall increases in precipitation associated with El Niño in the equatorial Pacific, the divergence at upper levels associated with this precipitation shows a future weakening at 200 hPa (left)
- This could result in weaker Rossby wave propagation from the equatorial Pacific to North America, and so a weakening of the El Niño anomalies in this region
- However, under future warming scenarios the tropopause height is expected to increase, so it could be that this divergence is occurring at higher levels
- Barotropic model experiments are currently underway to investigate the relative roles of changes in the basic state and changes in forcing strength on the teleconnection to North America

j.d.beverley@exeter.ac.uk @JBeverley93

WCRP CMIP6

World Climate Research Programme

Richard Wood

Met Office Hadley Centre

Met Office UKESM Natural Environment Research Council

Met Office

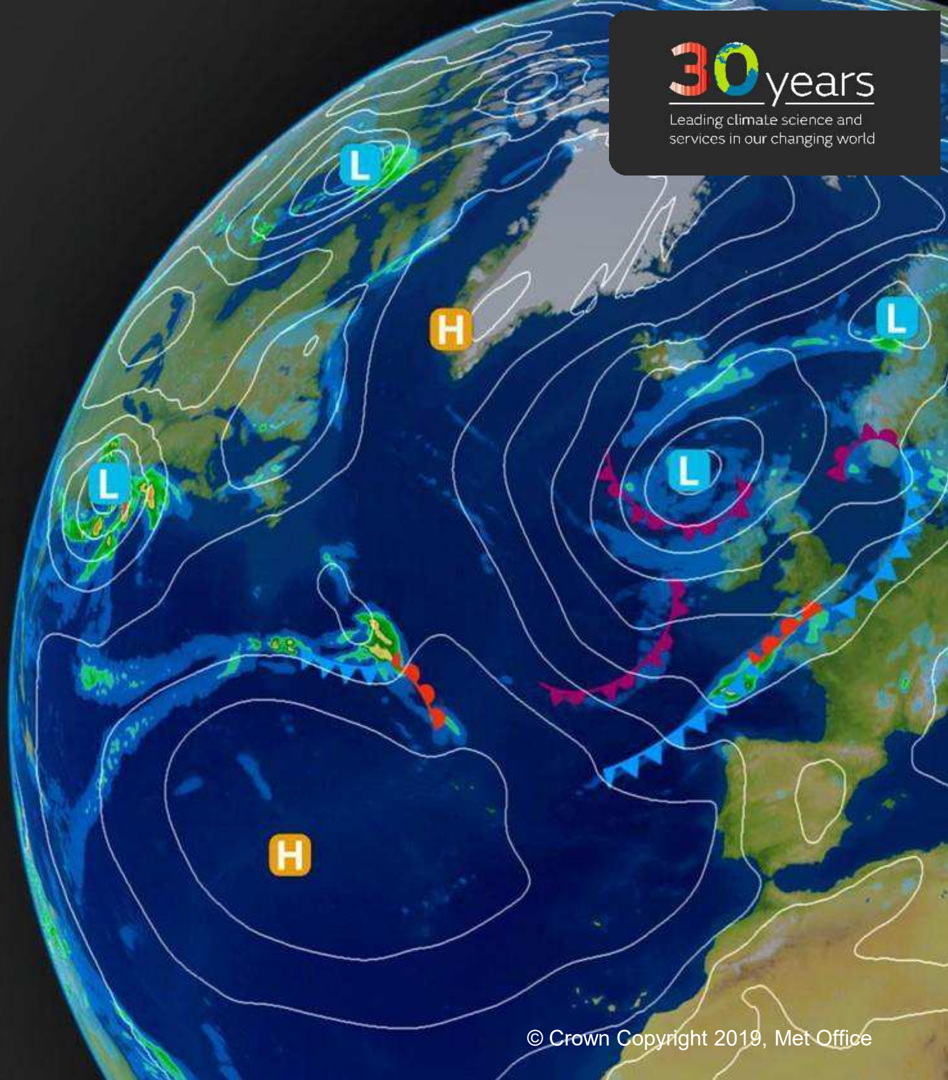
30 years
Leading climate science and services in our changing world

Understanding the simulation of historical global temperature in the UK CMIP6 models

Richard Wood[1]

with thanks to Tim Andrews[1], Martin Andrews[1], Jonathan Gregory[1,2]

[1]Met Office Hadley Centre, UK
[2] NCAS, University of Reading



Historical simulation of GMSAT 1850-2014

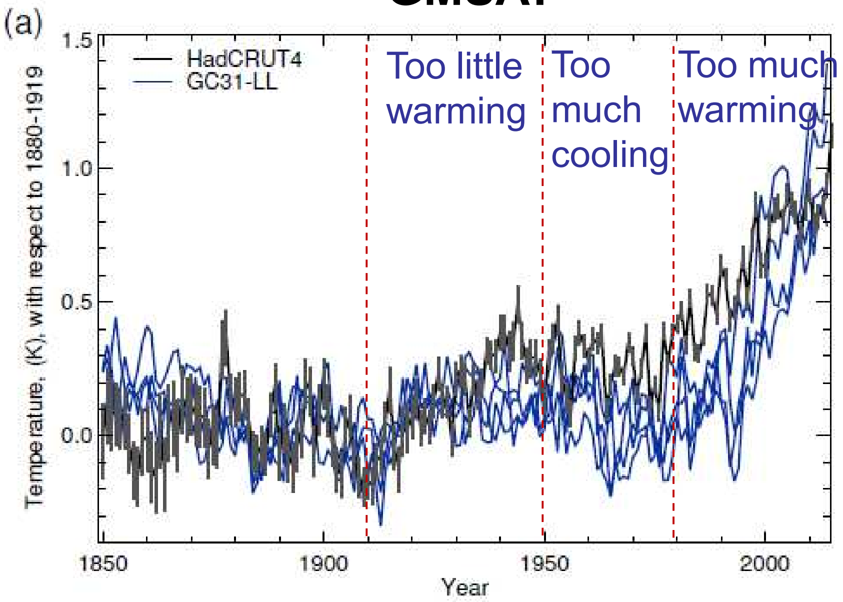
GC3.1-LL shown. GC3.1-MM and UKESM1 look similar

Simple analysis from M. Andrews et al 2020 JAMES (accepted)

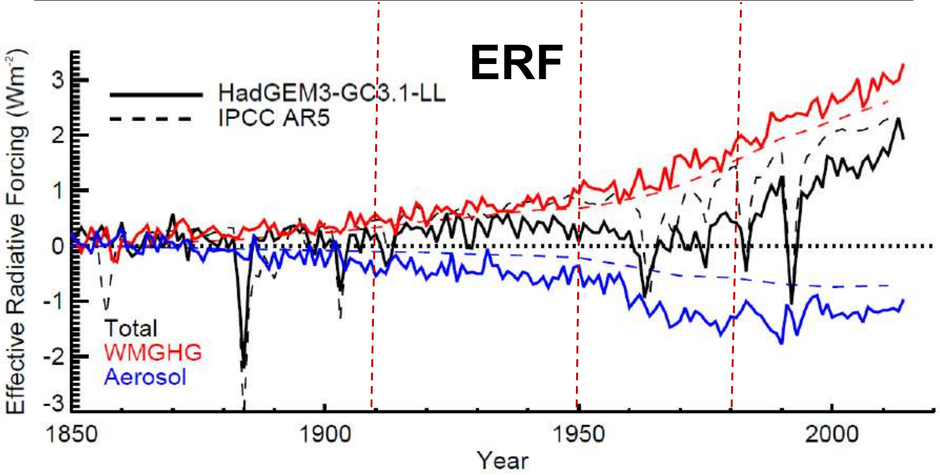
Energy balance diagnostic framework:

N	= F	- α.T
TOA(t)	Eff Rad Forcing (t)	Cl. Feedback Param (t)

GMSAT



ERF



Time dependence of α

Met Office
Hadley Centre

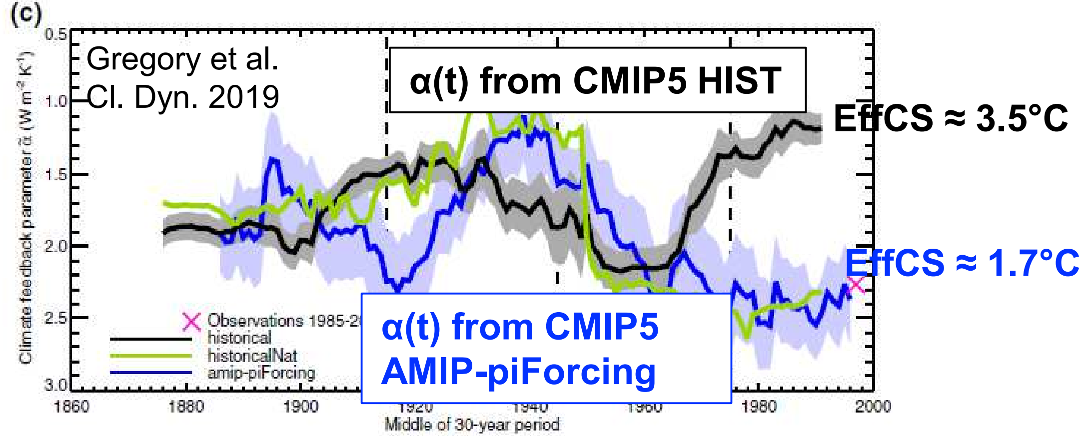
Estimate α by regressing T against N-F over a moving 30-year window

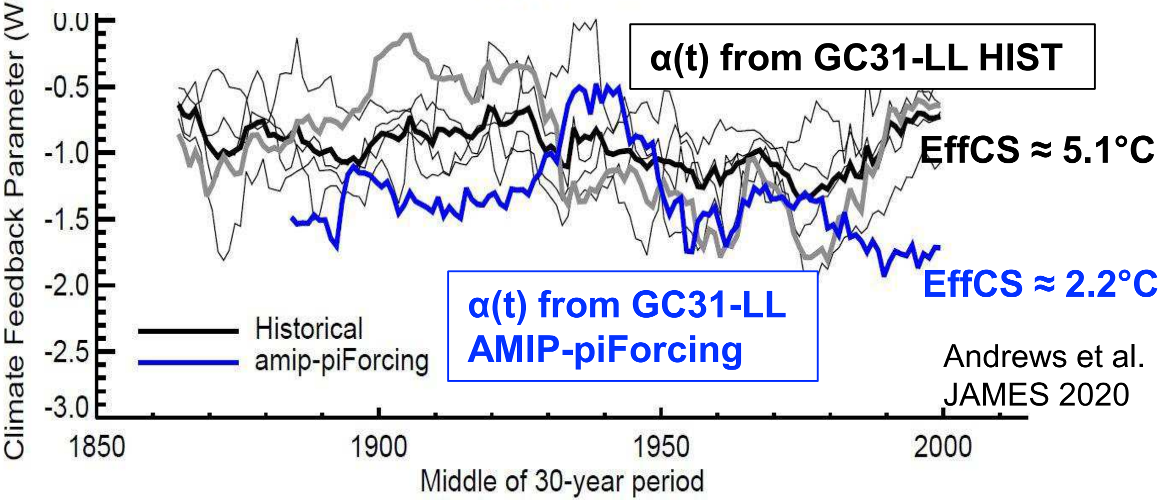
α varies by a factor of 2 over the HIST period

***AMIP-PIForcing* suggests that recent decades have been a period of low EffCS.**

Coupled HIST runs do not reproduce this (CMIP5 or GC31-LL) and have high recent EffCS

This is a much bigger source of error than the overall higher EffCS in GC3.1





Conclusions

References:
Gregory, J.M et al., 2019: How accurately can the climate sensitivity to CO2 be estimated from historical climate change? *Clim. Dyn.*, https://doi.org/10.1007/s00382-019-04991-y
Andrews, M. et al., 2020: Historical simulations with HadGEM3-GC3.1 for CMIP6. JAMES (accepted)

A hypothesis:

Early 20th Century warming: too strong increase in aerosol forcing (+ int var?)

1950-80 cooling: too strong increase in aerosol forcing

Post-1980 warming: EffCS *in the period 1980-2014* too strong

- Most likely explanation for this is incorrect simulation of time-varying component
- *Cannot* deduce from HIST GMSAT that the overall climate sensitivity is too high in this model

More work needed to understand HIST simulation and improve for next model:

- Focused PEG being set up to address this.
- Phase 1: improve understanding of HIST simulation
- Phase 2: deliver well-founded improvements for next generation UK model (late 2022)
- Followup from workshop May 2019. Hope to attract wide community interest and input

WCRP

World Climate Research Programme

CMIP6

Ranjini Swaminathan

University of Reading

Met Office

UKESM

UKRI

Natural Environment Research Council

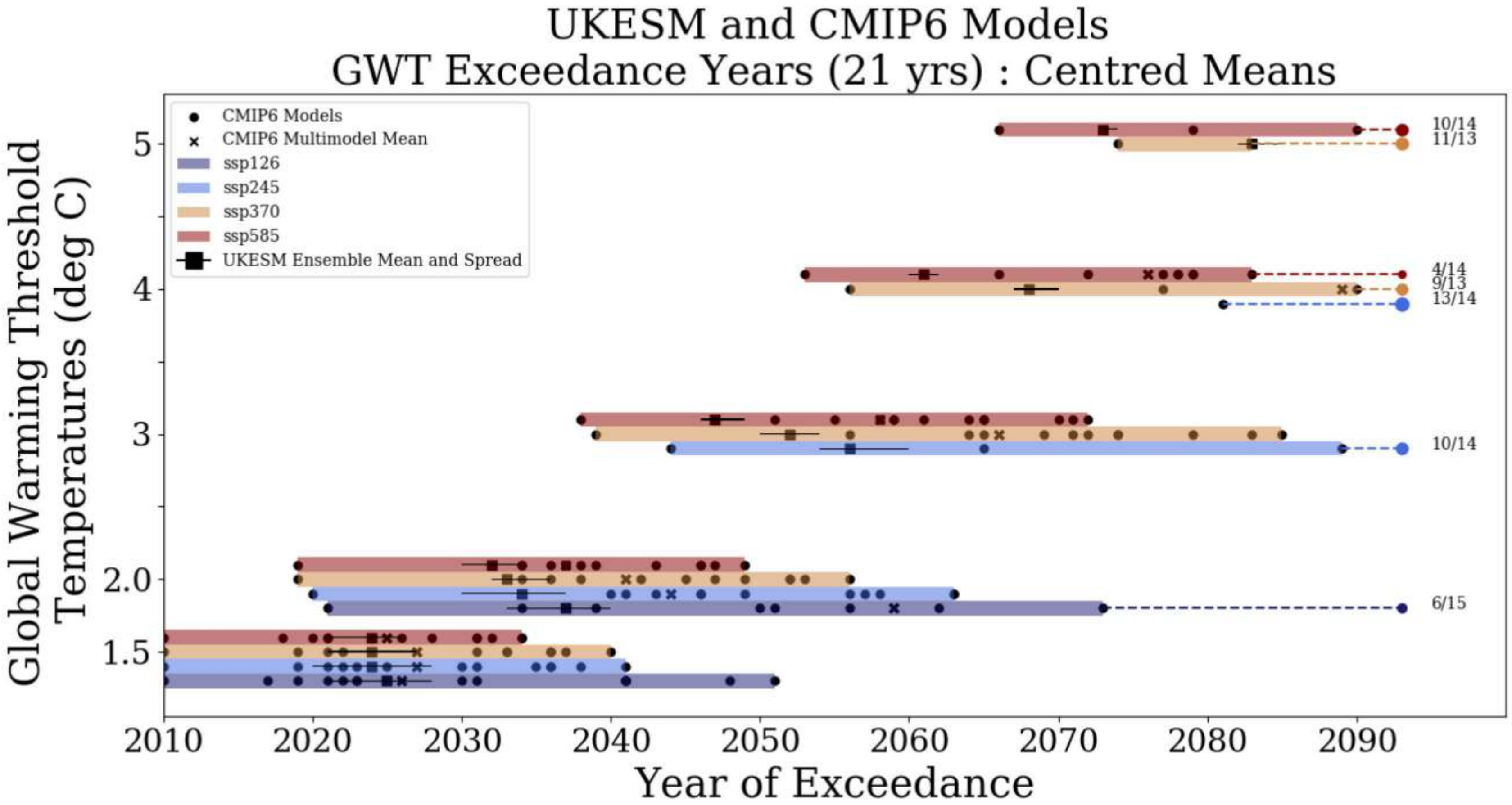
Regional Climate Change at Different Levels of Global Warming in the UKESM1 ScenarioMIP Ensemble

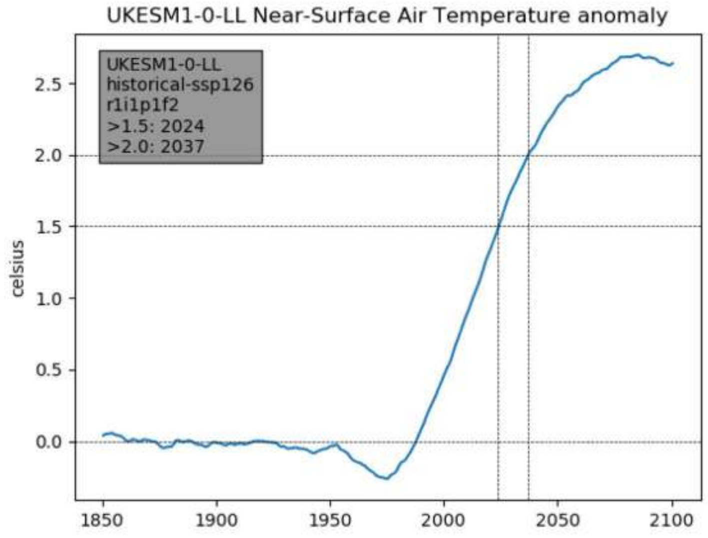
Ranjini Swaminathan, Colin Jones, Rob Parker, Richard Allan, Lee de Mora, Jeremy Walton, Douglas Kelley and others

UKESM

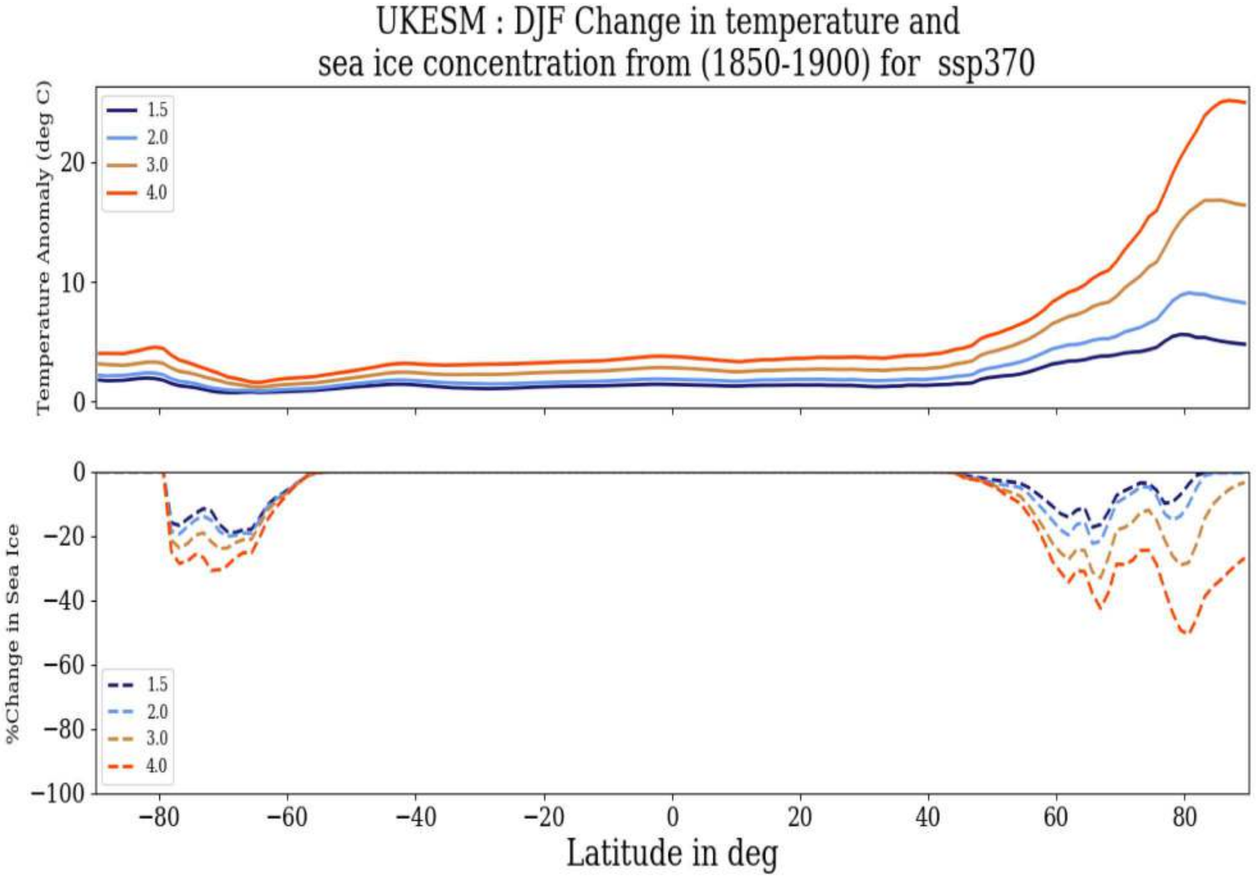
ESMValTool
Earth System Model eValuation Tool

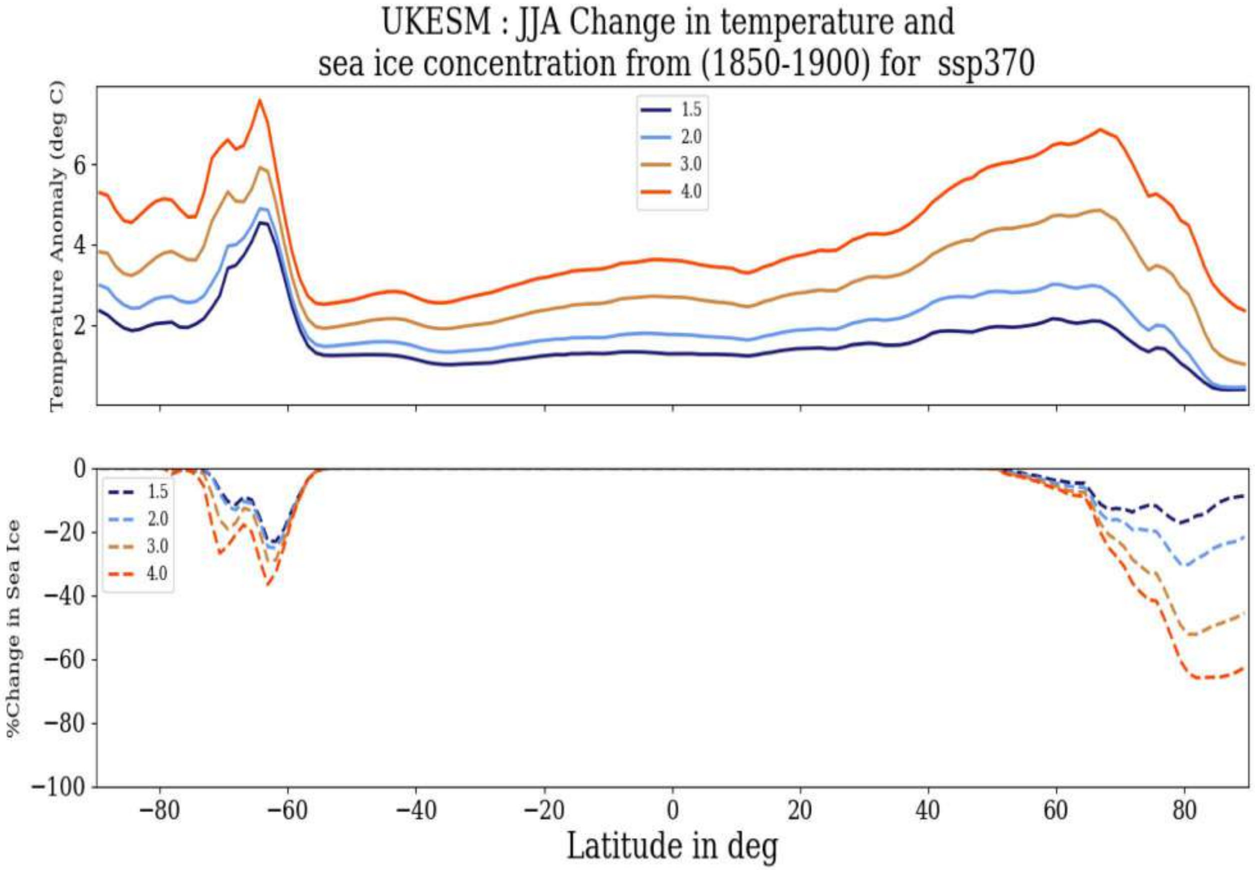
Global Warming Threshold Exceedance Years



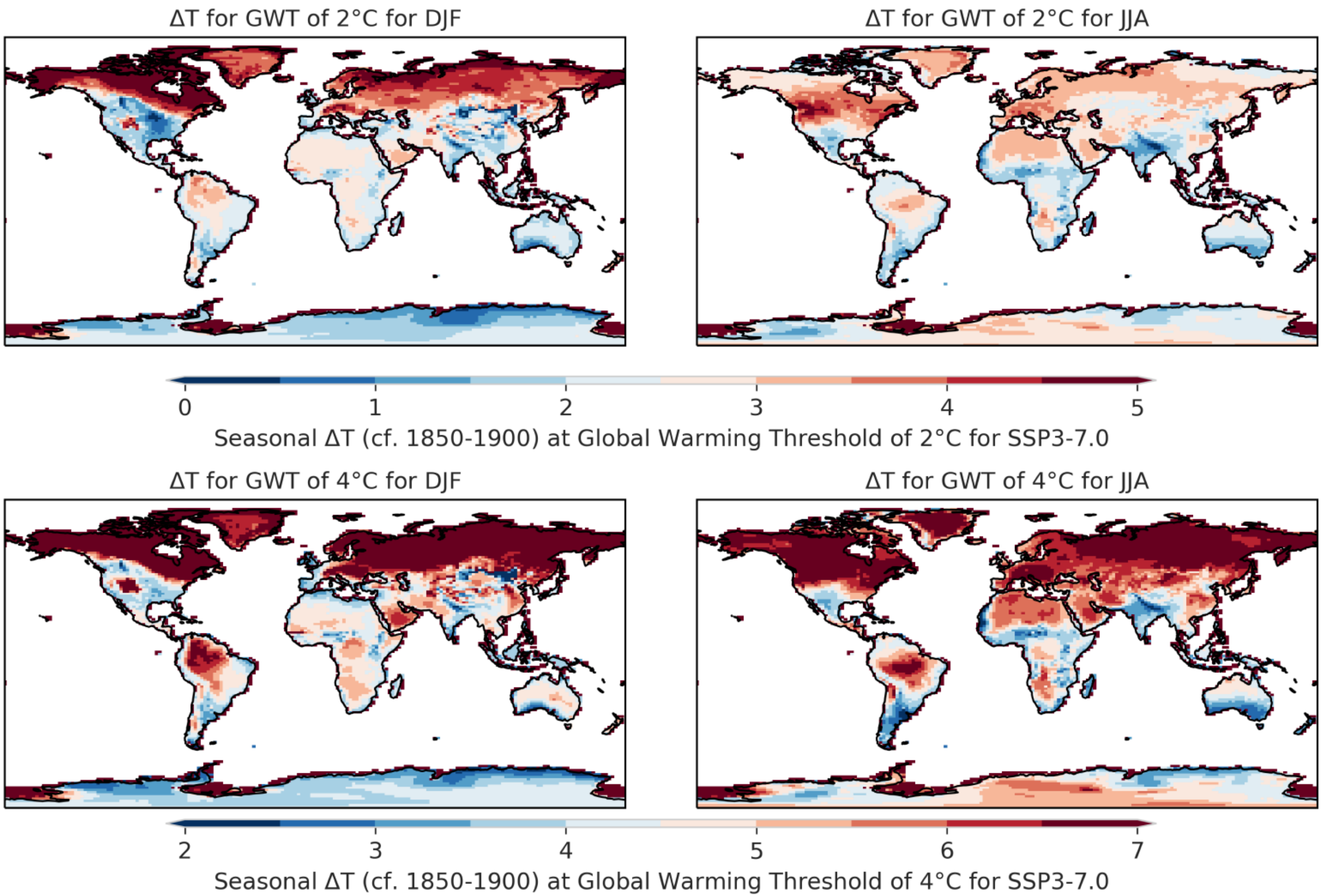


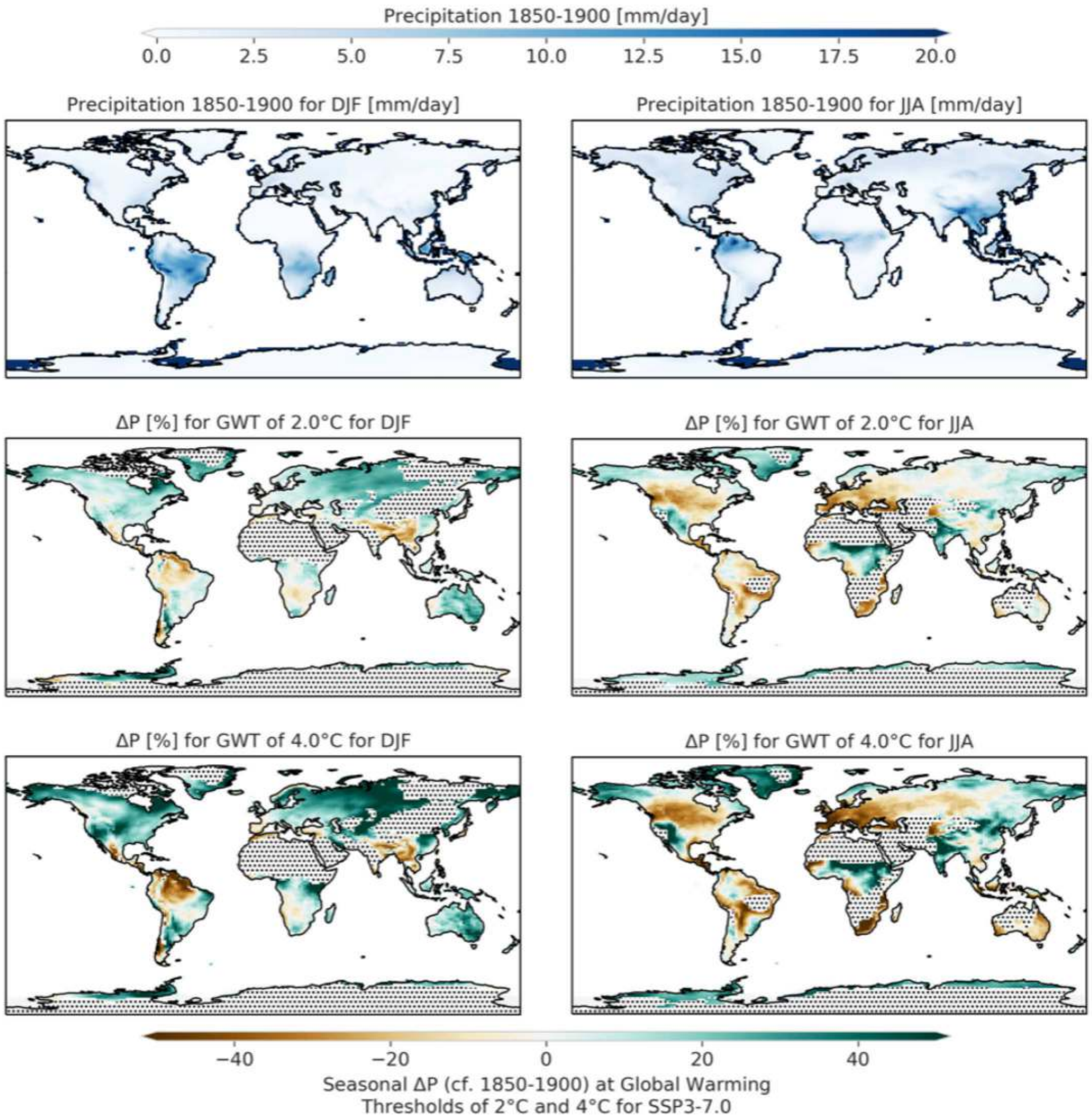
Zonal Mean Anomalies - Surface Temperature and Sea Ice Percentage





Changes in Land Surface Temperatures Around Threshold Exceedance Years





Changes in Precipitation over Land Around Threshold Exceedance Years

(stippling shows regions masked out where there is low historic precipitation (<0.5mm/day))

WCRP
World Climate Research Programme
CMIP6

Taraka Davies-Barnard
University of Exeter

Met Office
UKESM
UKRI Natural Environment Research Council

T's CMIP6 Biological Nitrogen Fixation QUIZ

T Davies-Barnard

+ other authors who may wish to take no responsibility for this:

Pierre Friedlingstein, Victor Brovkin, Yuanchao Fan, Rosie Fisher, Chris Jones, Hanna Lee, Daniele Peano, Benjamin Smith, David Wårlind, Andy Wiltshire, Sönke Zaehle, and Tilo Ziehn

CRESCENDO

UNIVERSITY OF EXETER

t.davies-barnard
@exeter.ac.uk

Q1: How does BNF fit into the modelled terrestrial C and N cycle?

a) N is an essential nutrient for plant growth and carbon uptake, and BNF is the main natural source of N. The amount of N available will potentially limit how much atmospheric carbon dioxide could be taken up by the terrestrial biosphere in future.

b) BNF comes from nodules on legumes and other plants in symbiotic relationships with N fixing bacteria and is highest in tropics.

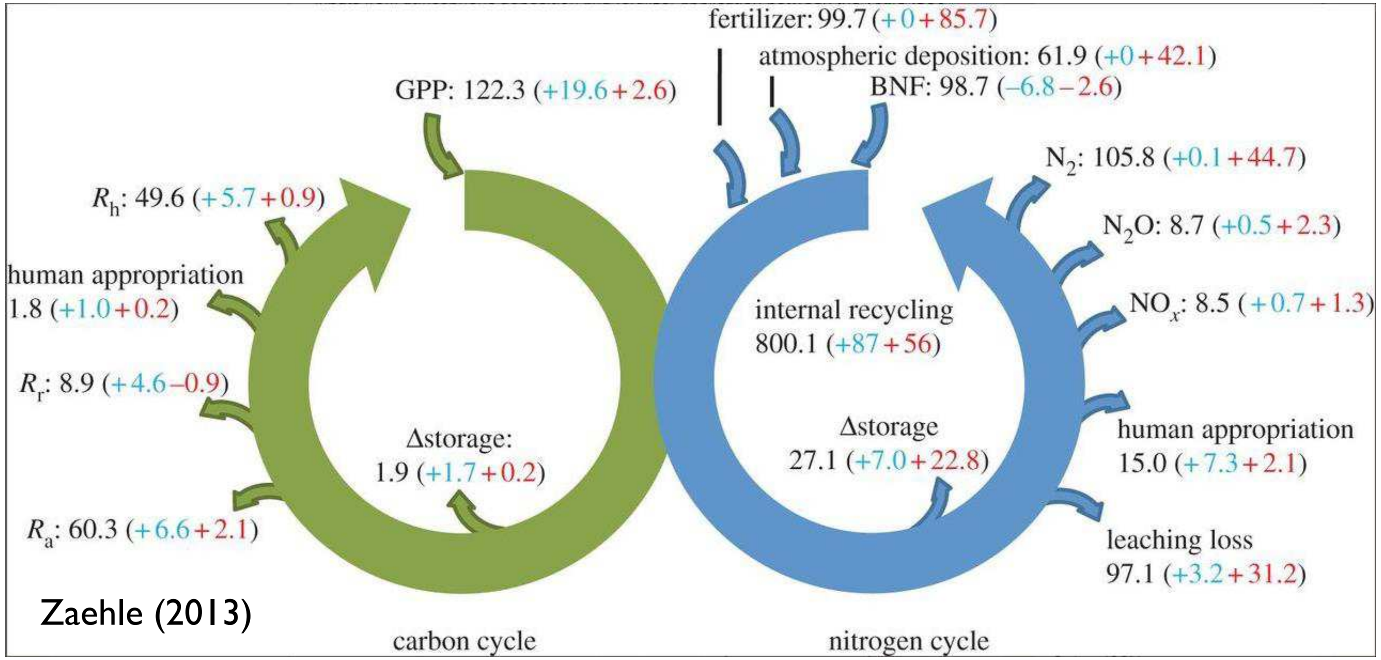
c) N is the next thing on the endless list of model developments and CLM had it in CMIP5, so now all models have to include it.

Yes, the answer is **a**.
Although BNF is best known as being the nodules on plants like clover, BNF occurs in significant quantities in both symbiotic and free-living situations, and in an array of places, from soil, canopy, plant stems, moss, lichens, and leaf litter.
BNF is heterogeneously distributed, with no natural strong spatial pattern (see right).
Because of its importance and connection to the C cycle, (see below) an N cycle has been added to 9 CMIP6 ESMs.

Q2: What is the most common empirical relationship for BNF in ESM/LSMs?

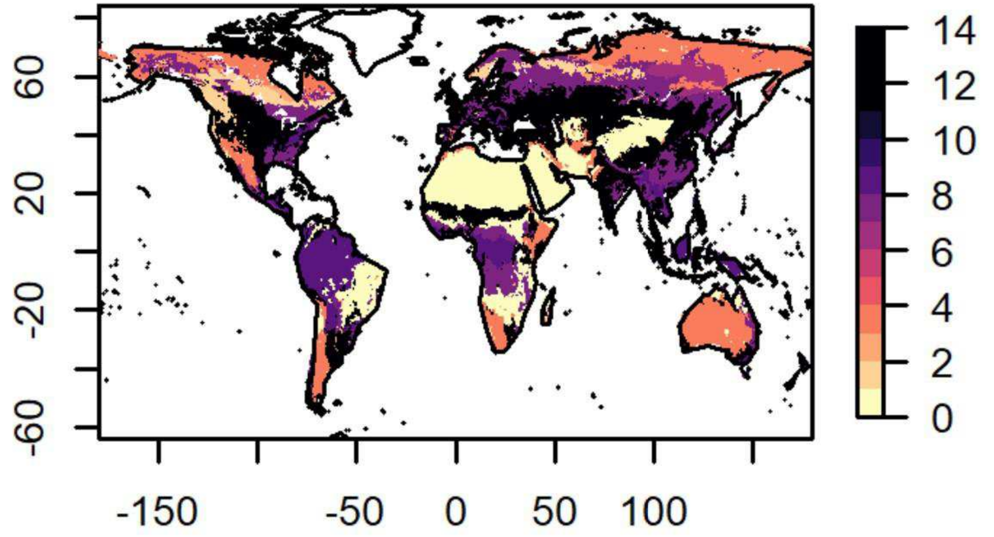
a) ET (evapotranspiration)
b) NPP (net primary productivity)
c) Cheeseburgers

C & N cycles, relative size of contributions



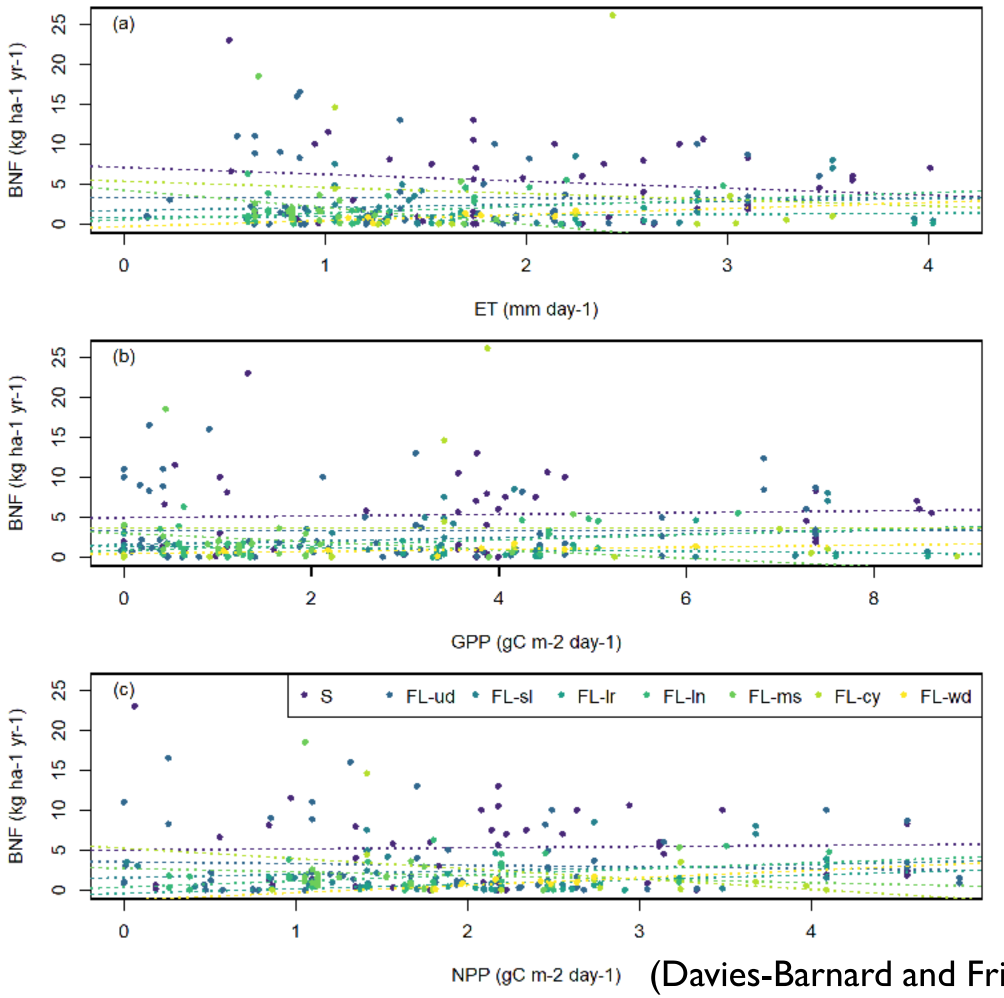
Zaehle (2013)

Biome BNF in kgN ha^{-1} yr^{-1}



(Davies-Barnard and Friedlingstein 2020)

Though all are good answers, **b** is correct.
Most models use a simple empirical function of NPP for BNF (see table, right). NPP and ET are popular options, but research has shown the relationship between BNF and NPP or ET to be weak (see below).



(Davies-Barnard and Friedlingstein 2020)

Q3: What is the (rounded) present day range of BNF in ESMs?

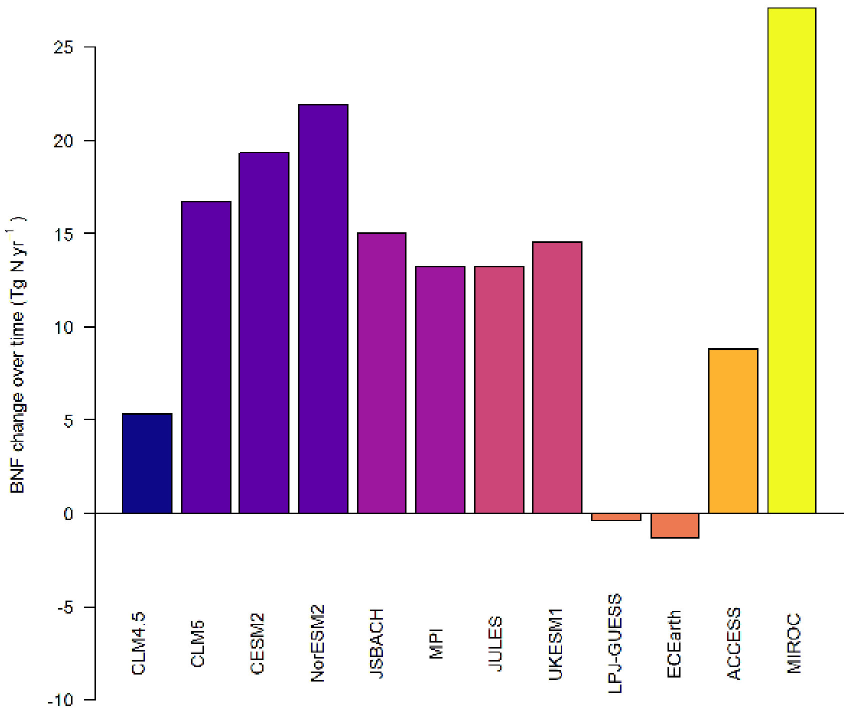
a) Because the overall integrity of our models is reliant on the accuracy of each individual component.
b) Because different assumptions lead to different amounts of BNF under high CO2 scenarios, and since the future allowable emissions rely (partially) on how much terrestrial carbon can be taken up, indirectly changes in BNF are policy relevant.
c) Because correlation is not causation.
d) All of the above.

Model BNF functions

NPP - direct	NPP - indirect	ET
JULES-ES & UKESM1	CLM5 & CESM2 & NorESM2	LPJ-GUESS & EC-Earth
CLM4.5 & CMCC-CM2	ACCESS	MIROC
JSBACH & MPI-ESM		

The answer is **d**, all of the above.
But the biggest issue for BNF is that if we are getting the 'right' (or an acceptable) present day value for the wrong reason, we cannot have confidence in projections of future changes.
We can see the importance of this by comparing the change in BNF from 1950-59 to 2005-2014 (below), where models hindcast a large range of changes (-3% (ECEarth) to +50% (NorESM)).

CAUTION, preliminary results. Right: Total global BNF anomaly 2005 – 2014 compared to 1950-1960, per year in CMIP6 models and corresponding LSMs (using CRUNCEP forcing).



Conclusions

- The basis of modelled BNF (NPP, ET, etc) really matters for the change over time, but has little relationship with the absolute amount of BNF in the model
- Some ESMs vary substantially from their LSM, possibly because the function is reliant on a variable that is different between CRUNCEP and GCM forcing.

The quiz is just a bit of fun. Why not share your score in the comments?

References:
Zaehle, S. Terrestrial nitrogen–carbon cycle interactions at the global scale. Philosophical Transactions of the Royal Society of London B: Biological Sciences 368, 20130125 (2013).
Davies-Barnard, T. and Friedlingstein, P.: The Global Distribution of Biological Nitrogen Fixation in Terrestrial Natural Ecosystems, Global Biogeochemical Cycles, 34(3), e2019GB006387, doi:10.1029/2019GB006387, 2020.